

The Power of Exploratory *Chandra* Observations

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Abstract. With its excellent spatial resolution, low background, and hard-band response, the *Chandra* X-ray Observatory is ideal for performing exploratory surveys. These efficient, sensitive observations can place constraints on fundamental properties of a quasar continuum including the X-ray luminosity, the ratio of X-ray to UV power, and the X-ray spectral shape. To demonstrate the power of such surveys to provide significant insight, we consider two examples, a Large Bright Quasar Survey sample of broad absorption line quasars and a sample of Sloan Digital Sky Survey (SDSS) quasars with extreme C IV blueshifts. In both cases, exploratory *Chandra* observations provide important information for a physical understanding of UV spectroscopic differences in quasars.

1. Introduction

X-ray emission appears to be a universal signature of quasar spectral energy distributions, confirming expectations from accretion physics. Based on rapid variability of soft X-rays in conjunction with the standard black-hole paradigm, these photons are believed to be emitted from the region immediately surrounding the black hole. Energetically, X-rays are significant, contributing 2–20% of the bolometric luminosity. X-ray observations are thus an important component of any multi-wavelength campaign to probe quasar populations.

The excellent spatial resolution of the *Chandra* High Resolution Mirror Assembly and the effective background rejection of the ACIS instrument make this combination uniquely powerful for quasar surveys. For reference, during a 5 ks observation, the 0.5–8.0 keV background within a 2''-radius source region is typically ~ 0.1 ct. Because ACIS is photon-limited even beyond 100 ks (Alexander et al. 2003), the point-source detection limit scales *linearly* with exposure time, unlike the \sqrt{t} dependence common in other wavelength bands. In conjunction with sub-arcsec positional accuracy, known optical point sources can be robustly

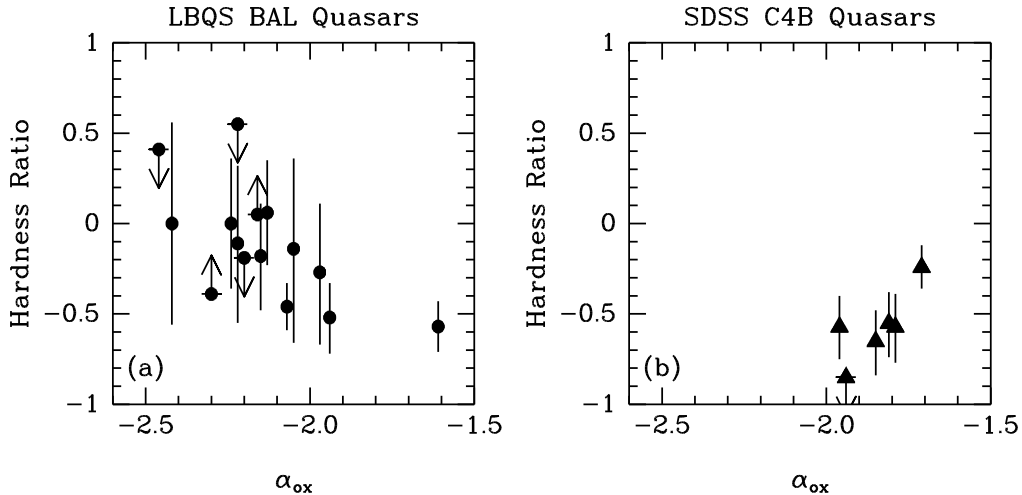


Figure 1. Hardness ratios versus α_{ox} from exploratory *Chandra* surveys for two quasar samples. (a) The Large Bright Quasar Survey broad absorption line quasar sample (Gallagher et al. 2003). (b) The SDSS C iv blueshift sample (Richards et al., in prep.).

detected with 3–5 photons. In 5 ks, this corresponds to a 0.5–8.0 keV flux of $\sim 7 \times 10^{-15}$ erg cm $^{-2}$ s $^{-1}$ for a typical quasar X-ray spectrum.

A 3–7 ks *Chandra* exposure, the regime of exploratory observations, is generally insufficient for gathering enough X-rays for spectral analysis of a quasar. However, the strategy of exploratory observations enables the extension of results from spectroscopic observations of individual targets to larger, well-defined samples, and the investigation of connections between X-ray properties and other wavelength regimes. From these datasets, standard X-ray observables are 0.5–8.0 keV flux, hardness ratio,¹ and α_{ox} .²

We briefly describe the initial results from two exploratory *Chandra* quasar surveys to illustrate the utility of this observing strategy. Other examples in the literature of successful applications of this approach to quasar studies include surveys of high- z (e.g., Brandt et al. 2002; Vignali et al. 2003), red (Wilkes et al. 2002), and X-ray weak (Risaliti et al. 2003) quasars.

2. X-ray Insights from the LBQS BAL Quasar *Chandra* Survey

We are in the process of performing the largest exploratory survey to date of a well-defined sample of broad absorption line (BAL) quasars drawn from the Large Bright Quasar Survey (LBQS). Since BAL quasars are known to be very faint X-ray sources (e.g., Green & Mathur 1996; Gallagher et al. 1999), ex-

¹The hardness ratio is defined to be $(h - s)/f$, where $h=2-8$ keV ct, $s=0.5-2.0$ keV ct, and $f=0.5-8.0$ keV ct.

²The quantity α_{ox} equals $0.384 \log(f_X/f_{2500})$ where f_X and f_{2500} are the flux densities at rest-frame 2 keV and 2500 Å, respectively.

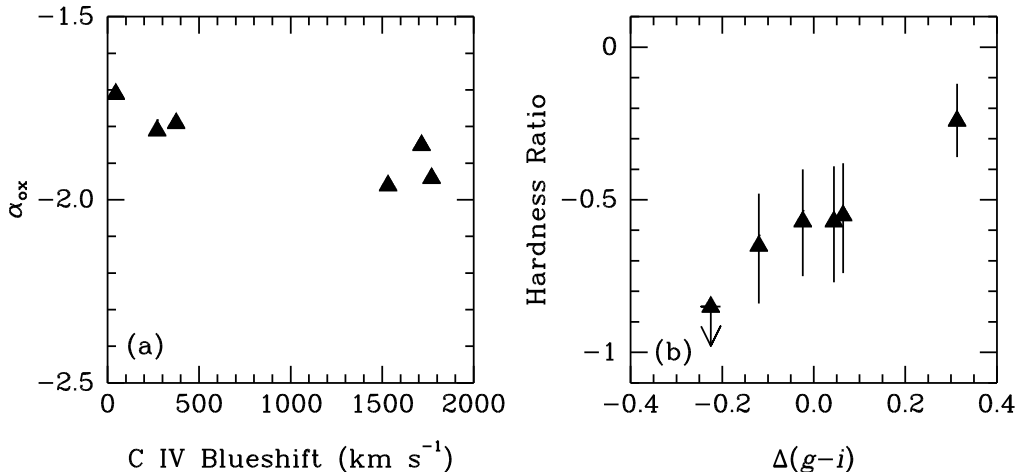


Figure 2. Measured X-ray properties from the C4B *Chandra* survey versus UV properties. (a) α_{ox} versus C IV blueshift. (b) Hardness ratio versus $\Delta(g-i)$ color. Redder colors are to the right.

exploratory observations are the only means of observing sufficient numbers to determine the X-ray properties of the population as a whole. The *Chandra* data alone are revealing. As seen in Figure 1a, the hardness ratio appears to be anti-correlated with α_{ox} . This indicates that the X-ray weakest BAL quasars have the hardest spectra, consistent with the understanding from spectroscopic observations of a handful of objects (e.g., Gallagher et al. 2002) that the X-ray spectra are heavily absorbed. Examining the connection between the X-ray and UV absorption properties of the quasars has also placed observational constraints on quasar disk-wind models (Gallagher et al. 2003).

In addition to exploratory *Chandra* observations, this sample is also being targeted by both SCUBA (PI Priddey) and *SIRTF* to characterize the submm through hard X-ray spectral energy distributions of BAL quasars as a whole.

3. The Connection Between C IV Blueshift and X-ray Properties

High-ionization broad emission lines such as C IV have been known to yield redshifts systematically lower than those measured from Mg II (e.g., Tytler & Fan 1992); i.e., these C IV lines are blueshifted relative to the systemic velocity. In a study of ~ 800 SDSS quasars with $1.5 \leq z \leq 2.2$, Richards et al. (2002) found that the C IV–Mg II velocity shifts ranges over ≥ 2000 km s⁻¹. Furthermore, the C IV blueshift (hereafter C4B) was correlated with UV properties, most notably the relative $\Delta(g-i)$ color (Richards et al. 2003). That is, the bluest quasars typically exhibited the largest C4Bs. Positing that the C4B might result from the orientation of the accretion disk or the opening angle of the disk wind, we proposed an exploratory *Chandra* survey to investigate this hypothesis.

Six targets, three each from the extreme ends of the C4B distribution, were approved for Cycle 4 observations. While any trends based on six data points need verification, the initial results from this small survey are intriguing.

ing. Figure 1b shows that hardness appears to increase with α_{ox} for the SDSS C4B quasar sample. Though this trend is not statistically significant (Spearman's rank-order correlation coefficient, r_s , is 0.67 for a significance level, p_{rs} , of 0.15^3), the fact that the hardest sources are not X-ray weaker is relevant. This suggests that the hardness of the spectra may not be due to intrinsic absorption in the same way as we see with the BAL quasars. Extending the study to the UV properties, we tested α_{ox} versus C4B and hardness ratio versus $\Delta(g-i)$ (see Figure 2). Though α_{ox} and C4B are consistent with being uncorrelated ($r_s = -0.77$, $p_{rs} = 0.07$), the hardness ratio is significantly correlated with $\Delta(g-i)$ ($r_s = -0.99$, $p_{rs} = 3 \times 10^{-4}$). As shown in Figure 2b, the bluer quasars appear to have softer X-ray spectra, i.e., more negative values of the hardness ratio. This is in line with expectation if UV continuum color is solely related to intrinsic obscuration. However, the lack of connection with α_{ox} makes this interpretation uncertain. The connection of UV spectroscopic properties to X-ray emission in these objects implies a physical connection, and more data to investigate this claim are certainly warranted.

This experiment also illustrates the value of the SDSS to multiwavelength quasar studies. Given the large number and uniform data quality of the available SDSS quasars, samples can be chosen with precision. Since hardness ratio can vary with z due to absorption and α_{ox} is a function of l_{2500} , the luminosity density at rest-frame 2500 Å (Vignali et al. 2003), sample tuning significantly reduces potential selection biases. In this C4B quasar survey, the redshifts range from $z=1.65$ – 1.89 and l_{2500} spans only a factor of ~ 5 . The properties of interest, in this case the C IV blueshift and $\Delta(g-i)$, are thus more reliably isolated for comparison with the X-ray emission.

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³The significance level ranges from 0.0–1.0 with a small value indicating a significant correlation.